CHAPTER 7 STUDY SCENARIOS AND SYSTEM RELIABILITY

7.1 Major Study Assumptions

After consultation with the groups working on energy demand, hydro, nuclear and thermal generation, the key modeling parameters were determined as follows:

- The main time horizon would be: 2000 – 2015, with a run-out year 2020.
- The country will not be divided by regions.
- Border transmission exchanges and power contracts with neighboring countries were included in the load forecast, except for Armenia-Iran power swap contract modeled explicitly.
- Because hydropower has a significant generation level in Armenia, all of the existing Sevan-Hrazdan and Vorotan cascade plants were modeled as individual plants.
- 15 existing and all potential thermal generating units were explicitly modeled.
- Vanadzor CHP plant was omitted from this Plan, since no sale of energy to the grid until 2010 is expected.
- All analysis is performed on Net basis (excluding auxiliary power consumption). Load forecasts are modified to be Net. Heat rates are modified to provide for auxiliary consumption. Capital and O&M expenditures are modified to account for auxiliary power consumption. All other relevant parameters are also modified to account for auxiliary consumption.

Financial Parameters

The discount rate used in the model was determined based on discussions with experts from the Armenian government, the World Bank, IFC, and EBRD. Two discount rates at 10 (base case) and 15 percent were used in the project.

All major projects are assumed to be financed by a mix of private and international bilateral/multilateral loans. The average annual interest rate is assumed to be 12%. Loan terms will assume re-payment of debt over a 10-year maturity. Accumulation or capitalization of interest takes place after the initiation of the project (IDC).

Load Forecasts

Load forecasts are discussed in Chapter 4. “Busbar” forecasts were modified by firm power contracts and DSM. Armenia- Iran swap was modeled explicitly.

Existing and Potential Builds

Existing units data is discussed in Chapter 3. Potential units data is presented in Chapter 8.

DSM

DSM contribution to the load forecast is discussed in Chapter 6.

Power Contracts Interflows:

	Iran	**Georgia**	**Artsakh**
Export Maximum (MW)	-200 (increased to -300 starting 2003)	-190	-31
Import Maximum (MW)	200 (increased to 300 starting 2003)	0	18

Seasonal exchange patterns are modeled based on the actual 1999 data.

7.2 Modeling Scenarios

The primary focus of this study is on the least-cost economic development alternatives for the Armenian generation sector. However, certain attention should also be paid to national issues related to fuel security in the region, generation type diversification, and reduction of dependence on imported energy sources. Additionally, it should be noted that energy security issues are outside of the scope of this study and are evaluated in a separate study currently prepared by the Government of Armenia under European Union funding. Therefore, two directions were taken in the modeling scenario preparation for this study. Most emphasis is given to the least-cost generation scenarios. However, several non-economical alternative sensitivities that can potentially provide greater long-term security to the operation of the Armenian energy sector were considered. With respect to the latter, no cost/benefit calculation is performed for the social and national effects of these sensitivities, as total financial costs are calculated only.

7.2.1 Least-Cost Scenarios Matrix of Study Cases

Table 1 below presents the mix of generation scenarios that were analyzed under the least-cost analysis.

Table 1 – Least-Cost Matrix of Study Cases

Case #	Demand Forecast			ANPP Retirement Year			Discount Rate		Fuel Forecast	
	Base	High	Low	2005	2010	2015	10%	15%	Base	High
1 Base	X			X			X		X	
2	X				X		X		X	
3	X					X	X		X	
4		X		X			X		X	
5		X			X		X		X	
6		X				X	X		X	
7			X	X			X		X	
8			X		X		X		X	
9			X			X	X		X	
10[1]	X			X			X		X	
1a		X		X				X	X	
2a		X				X		X	X	
3a			X	X				X	X	
4a			X			X		X	X	
1b	X			X			X			X
2b	X					X	X			X

The following assumptions are treated as common for all cases in the Least-Cost Matrix of Study Cases:

- Export/import arrangements are incorporated into forecast. Armenia-Iran swap is modeled explicitly.
- All rehabilitation/re-powering projects identified as “least-cost” in Chapter 8 are included
- New technology additions are from “least-cost” list derived in screening analysis (Chapter 8).
- Vorotan-Arpa tunnel is assumed to be completed by year 2004. Part of the water (about 260 GWh) is diverted from the Vorotan Cascade. This additional water is not used in the Sevan-Hrazdan Cascade until 2020 and goes into Lake Sevan in an effort to increase lake level.
- The ANPP decommissioning cost is assumed to be constant, and the cost distribution remains unchanged, independent of the eventual ANPP retirement date.

7.2.2 Strategic Scenarios Matrix of Study Cases

Table 2 below includes several cases for analyzing the impact on National energy security due to implementation of several alternative (possibly non-economic) measures.

[1] Case 10 is identical to Case 1, except for the target level of system reliability of 25% instead of 35%.

Table 2 – Strategic Scenarios Matrix of Study Cases

Case	Demand Forecast		ANPP Retirement Date		Fuel Price Forecast		Discount Rate
	Base	High	2005	2015	Base	High	10%
1s	X		X		X		X
2s	X			X	X		X
3s	X			X		X	X
4s		X	X		X		X
5s		X		X	X		X
6s		X		X		X	X
7s[2]	X		X			X	X
8s		X	X			X	X

The following assumptions are treated as common for all cases in the Strategic Scenarios Matrix of Study Cases:

- Export/import arrangements are incorporated into forecast. Armenia-Iran swap is modeled explicitly.
- All new projects identified as "strategic" in Chapter 8 are included. Completion/re-powering of Hrazdan Unit 5 and 82 MW CC CHP are included as near-term supply options.
- The Vorotan-Arpa tunnel is completed by year 2004. Part of the water (about 260 GWh) is diverted from the Vorotan Cascade. This additional water is not used in the Sevan-Hrazdan Cascade until 2016 and goes into Lake Sevan in an effort to increase lake level.
- The ANPP decommissioning cost is constant. The cost distribution remains unchanged, independent of the eventual ANPP retirement date.

7.3 System Reliability Analysis

7.3.1 Background

The task of developing an optimal expansion plan for the Armenian power system requires proper modeling of system reliability adequacy, while taking into account planned and forced outages of system components. It should be clearly understood that the system reliability discussed further reflects the reliability of generation system only and does not include T&D system reliability.

The Krzhizhanovski Energy Institute in Moscow was commissioned by Hagler Bailly to perform a reserve margin requirement assessment for the Armenian energy system within the framework of this Least-Cost Generation Plan. The computations of reserve margins under different scenarios were conducted by means of sophisticated computer models based on advanced mathematical combinatorial algorithms.

[2] Cases 7s and 8s use nuclear technology instead of hydro.

7.3.2 Reliability Model Inputs

Major components of the input data used for modeling include the following:

- Annual coincident peak load of end-use customers was escalated to account for losses in transmission and distribution networks;
- Typical hourly load curves of end-use customers for week-end and week-days by each season;
- Root-mean-square error of load forecast;
- Monthly peak loads of end-use customers escalated to account for losses in transmission and distribution networks and auxiliary power consumption of generators;
- Data on regional interflows between Armenia, Iran, Georgia and Karabagh by each hour of the year;
- Reliability level criteria;
- Data for each existing and proposed proxy units:
  - (a) Available capacity during monthly and annual peak hours;
  - (b) Forced outage rate;
  - (c) Average annual duration of short- and mid-term maintenance, and major overhauls.

7.3.3 Methodology of Reserve Margin Computation

The calculations of the reserve margin requirement were performed using sophisticated computer programs, which employed the approach of probability convolutions for calculation of the reserve margin. The following discussion provides the major formulas and theoretical approaches used.

The total reserve of active power of the system consists of two components:

1. The first component is the reserve required for current and mid-term maintenance and major overhauls. It is a common practice to conduct routine maintenance and major overhauls of the power plants during those periods when the customer load is relatively low. The required amount of maintenance and overhauls can be determined as MWh according to the following formula:

$$S_G = \sum_{i=1}^{f} N_i * t_i$$

where,
N_i – total available capacity of i-group of units;
t_i – duration of maintenance and overhauls
f – number of equipment groups.

The reserve for maintenance and overhauls is required only in the case in which S_G is bigger than the overall decrease of customer consumption during the periods of low end-use electric demand (S_L). In this case, the reserve for maintenance and overhauls can be determined according to the formula below:

$$\mathrm{Reserve}_{M\&O} = \frac{S_G - k * S_L}{12}$$

Where k (as per Russian norms) is assumed to be equal to 0.9-0.95

2. The second component is operating reserve. There are three factors which impact the value of required operating reserve:

- Reserve to replace equipment in a state of forced outage;
- Reserve to compensate deviations of the load;
- Reserve to secure error in load forecast.

Optimal operating reserve can be determined by minimizing the goal function consisting of three components:

- Construction cost of reserve capacity;
- Cost to maintain reserve capacity;
- Total losses for consumers due to blackout, assuming some pre-defined value of load loss.

For optimal operating reserves the integral probability of the capacity deficit is equal to:

$$J_{OPT} = \frac{\beta}{a * T}$$

where

β = discounted cost for construction and maintenance of reserve capacity for period T;
a = value of loss load for consumers.

The level of optimal operating reserves is defined by the following criteria:

$$J_{(r-1)} > J_{OPT} \geq J_r$$

where

$J_{(r-1)}$ and J_r are integral probabilities of capacity deficits for (r-1) and r MWs of operating reserve.

7.3.4 Major Modeling Assumptions

Modeling was conducted under the following additional assumptions:

- There is a degree of support from the Iranian power system in case of contingency events in Armenian system. The capacity of the interconnection between Armenia and Iran was assumed to be a maximum of 200 MW through the end of 2002, and a maximum of 300 MW starting in 2003 (upon reinforcement of the transmission system as per MoE comments);
- T&D system capabilities within the Armenian territory have no physical limitations on the delivery of maximum capacity;
- The medium peak demand growth scenario was used as the basecase assumption;
- The required reserve margin percent was calculated as the ratio of MWs of total reserve to MWs of *regular* annual peak load. Losses in transmission and distribution grids and auxiliary power consumption of generators were accounted for in this calculation.

  The regular annual peak load is determined according to the following formula:

$$P_{i,j}^{Reg} = \frac{\sum_{j=1}^{30} P_{i,j}^{Abs}}{30}, \; i \in [1,2,...,24]$$

  1. For each month of the year, the monthly regular peaks are calculated ($P_{i,j}^{Reg}$)
  2. Maximum value of monthly regular peaks is determined (P_{max}^{Reg})

$$P_{max}^{Reg} = \max[P_{i,j}^{Reg}]$$

Where
$P_{i,j}^{Abs}$ – hourly absolute peaks;
$P_{i,j}^{Reg}$ – monthly regular peaks;
P_{max}^{Reg} – annual regular peak;
i –hours;
j – days.

Assumptions on schedule of capacity additions of proxy units are provided below in Table 3.

Table 3 – Proxy Units Capacity Additions

	Reliability criteria 0.996 **(1.5 days or 35 hours per year)**
ANPP Decommissioning 2005	1. Combined Cycle unit 440 MW 2. Combined Cycle unit 400 MW
ANPP Decommissioning 2015	1. Combined Cycle unit 440 MW 2. Combined Cycle unit 400 MW

Proxy units were used in the analysis to provide realistic uniform ”standard” additions for the whole horizon of analysis. Normally, in utility practice the lowest cost units are used that best fit the system. They typically include large gas-turbines or “standard” combined cycle plants.

7.3.5 Scenarios Considered for System Reliability Analysis

An assessment of the reserve margin for the Armenian power sector for two base cases and four sensitivity scenarios was conducted. The two variables that tend to affect the reserve margin requirement most are:

- The decommissioning schedule of the Armenian Nuclear Power Plant in Medzamor (ANPP);
- Assumed reliability parameters for the generation units.

The following Table 4 describes the scenarios analyzed and lists analysis results reference tables.

Table 4 – Reserve Margin Evaluation Scenarios

	System Reliability Level (LOLP)		
ANPP Shut-down Year:	**0.996 (1.5 days/year)**	**0.986 (5.1 days/yr)**	**0.980 (7.3 days/year)**
2005	Base. Case #1. *Table 5*	Sensitivity. Case #3. *Table 7*	Sensitivity. Case #5 . *Table 7*
2015	Case #2. *Table 6*	Sensitivity. Case #4. *Table 7*	Sensitivity. Case #6. *Table 7*

It should be noted that the decimal system reliability level could be equated to days/year loss of load probability (LOLP). 1.5 days/year LOLP means that the load can be interrupted (not delivered) to all customers 1.5 days out of 365 days per year. Therefore, System Reliability Level = 1 – (LOLP/365 days per year). For example, System Reliability Level of 0.996 = 1 – (1.5 days per year / 365 days per year).

7.3.6 Rationale to use lowered reliability standards

While numerous Western countries have established higher reliability standards than those that have been are adopted for Armenia in this study (e.g., Australia - .9995, New England Power Pool - .99991), there are several reasons why the assumptions on lower reliability standards can be justified:

1. Forced outage rates of distribution lines will not allow the customers to enjoy higher levels of generation reliability.
2. Reliability criteria in some countries with relatively high living standards are lower than the 0.996 percent used in the Armenian base case study: Hungary - 0.9943, Brazil - 0.9932, South Africa (ESKOM system) - 0.9836.
3. Theory says that the lower reliability criteria are, the less impact it has on reserve margin. Given, that 0.996 is relatively high reliability standard, the potential impact of lowered reliability standard on reserve margin in Armenian case will be significant. Thus, the slight decrease in reliability level may result in large money savings and lower tariffs for customers. Special cases 10 and 19 in this study assume lower level of reliability. This assumption is an exercise to show how overall system reliability impacts long-term production costs in the system.
4. 0.996 percent is the level of reliability that was calculated in USSR given the high values of loss of load in the Soviet economy. This does not reflect realistically the reliability level currently required in Armenia. Obviously, in Armenia present values of loss load are much lower than those of the former USSR, except for a few reliability-sensitive industrial customers. Thus, the overall system reliability criteria could be lower as well.

7.3.7 Reliability Modeling Results

The following three tables present the results of reserve margin evaluations under various generation system reliability levels.

Table 5 - Base Case #1 (ANPP shut-down in 2005, system reliability level = 0.996 percent

Year	**Total Reserve Requirement**							
	MW				**%**			
	Reserve for mainten.	Reserve for major verhauls	Operating reserve	**Total reserve, MW**	Reserve for mainten.	Reserve for major overhauls	Operatin g reserve	**Total reserve, %**
2000	66	112	159	**337**	6,6	11,2	15,9	**33,7**
2001	64	98	189	**351**	6,2	9,5	18,3	**34,0**
2002	67	89	150	**306**	6,4	8,5	14,3	**29,1**
2003	67	85	52	**204**	6,2	7,9	4,8	**19,0**
2004	67	82	53	**202**	6,1	7,5	4,9	**18,5**
2005	118	101	170	**389**	10,6	9,1	15,3	**35,0**
2006	118	96	171	**385**	10,4	8,5	15,1	**34,0**
2007	110	85	172	**367**	9,5	7,4	14,9	**31,8**
2008	110	79	173	**362**	9,3	6,7	14,7	**30,7**
2009	110	72	176	**358**	9,0	6,0	14,6	**29,6**
2010	110	66	216	**392**	8,8	5,3	17,3	**31,4**
2011	110	58	218	**386**	8,6	4,5	17,0	**30,1**
2012	110	51	219	**380**	8,4	3,9	16,6	**28,9**
2013	127	60	218	**405**	9,4	4,4	16,1	**29,9**
2014	127	52	242	**421**	9,1	3,7	17,4	**30,2**
2015	127	43	237	**407**	8,9	3,0	16,6	**28,5**
Maximum Reserve Margin 2000-2010								***35.0 %***
Maximum Reserve Margin 2011-2015								***30.2%***

Table 6 - Case #2 (ANPP shut-down in 2015, system reliability level = 0.996)

Year	Total Reserve Requirement							
	MW				%			
	Reserve for mainten.	Reserve for major overhauls	Operating reserve	**Total reserve, MW**	Reserve for mainten.	Reserve for major overhauls	Operatin g reserve	**Total reserve, %**
2000	66	112	159	**337**	6,6	11,2	15,9	**33,7**
2001	64	98	189	**351**	6,2	9,5	18,3	**34,0**
2002	67	89	150	**306**	6,4	8,5	14,3	**29,1**
2003	67	85	52	**204**	6,2	7,9	4,8	**19,0**
2004	67	82	53	**202**	6,1	7,5	4,9	**18,5**
2005	101	111	120	**332**	9,1	10,0	10,8	**29,8**
2006	116	135	122	**373**	10,3	11,9	10,7	**32,9**
2007	116	129	123	**368**	10,1	11,2	10,7	**32,0**
2008	116	124	124	**364**	9,9	10,5	10,5	**30,9**
2009	116	117	127	**360**	9,6	9,6	10,5	**29,7**
2010	116	110	170	**396**	9,3	8,8	13,6	**31,7**
2011	116	103	172	**391**	9,1	8,0	13,4	**30,5**
2012	134	113	174	**421**	10,2	8,6	13,2	**32,0**
2013	134	105	270	**509**	9,9	7,7	19,9	**37,5**
2014	134	97	270	**501**	9,6	6,9	19,4	**35,9**
2015	127	43	237	**407**	8,9	3,0	16,6	**28,5**
Maximum Reserve Margin 2000-2010								***34.0%***
Maximum Reserve Margin 2011-2015								***37.5%***

Table 7 – Sensitivities (Cases # 3,4,5 and 6) – Three system reliability levels (0.996, 0.986, and 0.980) with ANPP retirement in 2005 and 2015.

Year	**0.996**				**0.986**				**0.980**			
	2005		**2015**		**2005**		**2015**		**2005**		**2015**	
	Total reserve		**Total reserve**		**Total reserve**		**Total reserve**		**Total reserve**		**Total reserve**	
	MW	**%**	**MW**	**%**	**MW**	**%**	**MW**	**%**	**MW**	**%**	**MW**	**%**
2000	337	33,7	337	33,7	210	21,0	210	20,95	165	16,5	165	16,47
2001	351	34	351	34	224	21,6	224	21,65	179	17,3	179	17,31
2002	306	29,1	306	29,1	179	17,0	179	16,98	134	12,7	134	12,71
2003	204	19	204	19	77	7,1	77	7,13	32	3,0	32	2,95
2004	202	18,5	202	18,5	75	6,8	75	6,82	30	2,7	30	2,72
2005	389	35	332	29,8	262	23,5	205	18,36	217	19,5	160	14,33
2006	385	34	373	32,9	258	22,7	246	21,65	213	18,8	201	17,70
2007	367	31,8	368	32	240	20,8	241	20,91	195	16,9	196	17,02
2008	362	30,7	364	30,9	235	19,9	237	20,08	190	16,1	192	16,27
2009	358	29,6	360	29,7	231	19,1	233	19,18	186	15,4	188	15,49
2010	392	31,4	396	31,7	265	21,2	269	21,49	220	17,6	224	17,91
2011	386	30,1	391	30,5	259	20,2	264	20,55	214	16,7	219	17,06
2012	380	28,9	421	32	253	19,2	294	22,31	208	15,8	249	18,90
2013	405	29,9	509	37,5	278	20,5	382	28,11	233	17,2	337	24,81
2014	421	30,2	501	35,9	294	21,1	374	26,76	249	17,8	329	23,55
2015	407	28,5	407	28,5	280	19,6	280	19,57	235	16,4	235	16,43

In summary, the following maximum total system reserve margins are observed in Table 7.

Table 8 – Summary of system reserve margins

	0.996		0.986		0.980	
ANPP Retirement	2005	2015	2005	2015	2005	2015
Maximum Reserve Margin 2000-2010	***35.0***	***34.0***	***23.5***	***21.6***	***19.5***	***17.9***
Maximum Reserve Margin 2011-2015	***30.2***	***37.5***	***21.1***	***28.1***	***17.8***	***24.8***

7.3.8 Conclusions

The target reserve margin that will trigger capacity additions in the system is evaluated at about 35% (for 0.996 system reliability level, 1.5 days/year). All modeling cases, except for Cases 10 and 19, will use this value as a benchmark.

Special Cases 10 and 19 will assume a lower level of generation system reliability of 0.980-0.986 and average reserve margin requirement of 25%. These cases are evaluated to show that lower system reliability provides lower system production costs and consequently lower costs to customers. The reasoning for lowering overall system reliability levels is presented in Section 7.3.6.